

Local and Holistic Electromagnetic Therapies

A. R. LIBOFF

Center for Molecular Biology and Biotechnology,
Florida Atlantic University, Boca Raton, Florida, USA

Based on decades of experimental evidence an excellent argument can be made for the existence of a fundamental functional relationship between living systems and electromagnetic fields. We have previously hypothesized that this relationship can be expressed in terms of a field vector whose source is the distribution of electric polarization within the system and which has both a phylogenetic and ontogenetic time dependence. Ion cyclotron resonance (ICR)-like magnetic signals have resulted in physiologic changes in many in vitro and in vivo model systems and have been applied medically with success to bone repair and spinal fusion. This type of local ICR-like therapy has recently been broadened into a holistic application following the remarkable discovery that the whole-body bioimpedance is sharply dependent on ICR signals. We relate this observation to the integrated electric polarization vector, in turn a measure of the double layer charge distribution at the cell membrane. This discovery, already being applied to a number of clinical problems, lends strong support to the concept of an overarching electromagnetic framework for living systems.

Keywords Double layer distribution; Geomagnetic field; Ion cyclotron resonance therapy; Polarization vector; Whole body bioimpedance.

Introduction

There is a very strong but also puzzling connection between living things and electromagnetism. Galvani and Volta, despite their bitter dispute, brought to light the fact that living things can generate electricity. Viewed from today's perspective, where many substances, living and non-living, can produce electricity, this is not very surprising. The one thing that was of long-lasting scientific interest is that Galvani opened the door to realizing that the nervous system is essentially electrical in character.

However Matteucci's later contribution in the 1830s may have even more lasting significance; it revealed the possibility for the first time of a functional relationship between electricity and homeostasis. Becker (1961) realized this when

Address correspondence to A. R. Liboff, Center for Molecular Biology and Biotechnology, Florida Atlantic University, Boca Raton, FL 33431, USA; E-mail: arliboff@aol.com

he used a number of examples to leap forward with a truly creative idea, that the “current of injury” first associated with Matteucci (1834), the change in electrical state following a change in the living system, is in reality part of a larger electrical mechanism. Becker is not the only one that should be mentioned in this context. Lund (1947), and later Jaffe (1968) made note of the electrical dipole character of young plants. Burr and Northrup (1935) reported changes in electrical surface potential in cancerous tissues, and Athenstaedt (1969) made precise measurements on fresh human bone taken from individuals of varying age, to show that there are changes in electric polarization in bone as we grow.

But although these were very important observations, it was Becker who first showed clearly that Matteucci’s current of injury had a physiological function. Using the salamander, which has a wonderful ability for regeneration, Becker (1961) surmised that the current of injury associated with amputation of the salamander arm is also the signal that guides the regeneration process. Becker (1974) went on to view the remodeling process in bone following a fracture as an extension of this electrical regeneration mechanism.

Later, Marino and Becker (1970) showed conclusively that bone remodels after it is broken using the piezoelectric polarization related to the gravitational force on bone. It is interesting to realize that this observation by Marino and Becker explained an orthopedic rule that had been set forth many years earlier, by Wolff (1892) at the Charite Hospital in Berlin, termed Wolff’s Law, stating that living bone always reshapes itself, accommodating to the force applied. This law states that bone, according to the stresses placed on it, is deposited and resorbed respectively by two types of bone cells. Bone deposition occurs because of osteoblasts, and bone resorption occurs due to osteoclasts. Using data reported by McElhaney (1967), Marino and Becker (1970) showed that osteoblastic and osteoclastic activity were tied to the sign and intensity of the piezoelectric polarization. This very important observation is rarely mentioned today. But, considering the present intensive interest in stem cells, it should be carefully reviewed, because one implication of this work is that electric fields can have a determining effect on cell differentiation.

During the 1960s the electrical properties of living bone were brought to light, and this led to the realization that one can apply electric currents to initiate growth processes in bone (Lavine et al., 1972), much as occurs naturally as a consequence of Wolff’s Law. The successful use of microampere level currents was followed in this regard by equally efficacious currents induced by external magnetic fields, then currents induced through “capacitive coupling”, and finally extremely weak low frequency magnetic fields, as ion cyclotron resonance exposures (Diebert et al., 1994). In view of this array of observations on the capacity of electric and magnetic fields to influence bone metabolism it is truly remarkable how little impact this has had on bone physiologists, who continue to disregard the electromagnetic nature of the effects, instead attempting to frame these effects in familiar terms.

Life as an Electromagnetic Phenomenon

In 1994 we wrote (Liboff, 1994)

... does the ability of weak ELF signals to perturb living systems indicate that these signals are interacting with an intrinsic electromagnetic characteristic of these systems?...do living systems contain a hidden electromagnetic variable?

I believe that there is indeed a hidden electromagnetic character to life, in fact, that the underlying order of life is an electromagnetic phenomenon. I mean this in a literal manner. Let me expand on my reasons for this strange way of thinking.

Life is an expression of the electromagnetic force. We can regard life, i.e., the special quality attached to all living systems, as a consequence or as an extrapolation of what physics calls the electromagnetic field of force. In our view of the world there are only four types of force: the *nuclear*, the *electromagnetic*, the *weak*, and the *gravitational* force. Theoreticians have combined some of these, in the hope of writing one unified expression, into what is sometimes called the Theory of Everything. But until that glorious day, we limit ourselves to these four well understood forces. Each of these forces has certain observational consequences. For example, the fact that the planets move in well described orbits around the sun or that an object thrown up in the air will fall back to earth is a consequence of the gravitational force. The fact that collections of protons and neutrons will stick together to make atomic nuclei is a consequence of the nuclear force. The fact that a neutron at rest will decay in 11 minutes to form an electron and a proton is a consequence of the weak force. It is also a fact that we observe stable collections of charged nuclei and electrons that we call atoms. This is a consequence of the electromagnetic force. It is possible to find other such examples, and even to group these into a sort of series, each increasing in complexity, but each still a consequence of the electromagnetic field of force. Thus we can form the following sequence, expressing life as the most recent realization of the electromagnetic force.

1. Charged particle interactions: electrons, protons, . . .
2. Atom formation: combinations of electrons, charged and uncharged nucleons
3. Molecular formation: combinations of atoms
4. Organic molecules: proteins and sugars, covalent and hydrogen bonds
5. Polymers: long chains of organic molecules
6. Self replicating polymers: DNA/RNA

Biology is overly anthropomorphic. For hundreds of year, biological observation has depended on what are still called visible characteristics. Speciation is dependent on things like the size of the beak in birds, the shape of the jawbone in primates, the location of fins in fish, and countless other attributes that allow us to differentiate one living system from another.

Of course all sciences begin with visual observation. But they have to advance beyond this initial state. Because of its reliance on visual observation biology is in many ways not too different from the social sciences, where everything is viewed in human terms. This reliance on traits to describe differences even extends to genetics, where we classify genes in terms of how they control visual traits.

The question that I put to you is: can matters like speciation be rephrased in ways that do not reflect the fact that humans are the observers? How can we make biology a more objective science?

Is biology too complex? It is one thing to describe things down to the finest details. No one ever objects to careful analysis. But if there is no accompanying synthesis of these details, no generalization that ties all the details together the net result is an incomplete science. This is not to recognize that there have already been a number of key generalizations in biology that have resulted in great insights.

The greatest of these is undoubtedly Darwin's gift of natural selection. But there is also the theory of the cell, initiated by Marcello Malpighi in 1660, and put into final form by Schwann in 1839. And of course because of Watson and Crick and their discovery of the genetic code we now understand how characteristics are genetically transferred. This area has come to be known as molecular biology.

Unfortunately one finds that biochemical description becomes an end in itself in molecular biology. Even the attacks by creationists on Darwinian evolution reflect this biochemical point of view. The biochemist Behe (1996) has argued that natural selection cannot account for certain highly complex features in living things. These are said to suggest an "irreducible complexity" that cannot have resulted from evolutionary processes alone. One favorite example is the structure of the mammalian eye. Yes, the eye is a remarkable biological accomplishment. But its complexity can be viewed in different ways. As seen by a biochemist it is a highly organized collection of specifically tailored molecules. However, perhaps biochemistry is not the simplest way to describe living structures. The language of the biochemist is essentially a laundry list of molecules and rules governing their interactions. True, this laundry list has groupings—there are shirts and blouses and trousers, but it is nevertheless still a long list of items within groups of proteins and sugars and nucleotides with little or no unifying character to the entirety. There are now thousands of known enzymes, a situation that brings to mind the remark by Poincare that if there were many more than 100 elements to the periodic table it would likely never have been discovered. Attempting to describe the eye in biochemical terms is an exercise in futility.

By contrast, we prefer to think of "complex" biological structures like the eye as multipole expansions of electric fields that govern the choice of organic molecules that make up the structure. In other words it is much simpler to think of an electromagnetic template that chooses among the sea of available molecules for the grouping that best forms the eye. The "complexity" of the structure is then merely expressed as the numerical exponent of the highest term in a series expansion.

Can we express a theory of wellness in electromagnetic terms? There is presently no general theory of wellness and illness. Medicine is purely empirical. We give pills, we cut the body apart to either remove things or add them; we replace bad organs, like the heart, the kidneys, the lungs. Presently we are experimenting with gene therapy, attempting to replace "bad" genes with "good" ones. The next step perhaps will be for physicians to add stem cells in situ to diseased organs, hoping that these will differentiate into healthy cells. All these advances are truly wonderful, giving patients who might otherwise be doomed to die a new chance in life. But nowhere in this impressive list of medical accomplishments is there any hint of an all-encompassing model of wellness, something to transcend all these specific solutions.

Consider the problem of cancer. The war on cancer has been fought with billions of dollars for research each year for many years, and yet, after all this time, we are still told that the best way of fighting cancer is to identify the cancer at an early stage. This is the very best that can be done by the experts in cancer. We still do not know how to alter the response of our immune system, either to make it stronger when challenged or to prevent it from over reacting in autoimmune problems. When dealing with bacterial infections, simple pneumonia for example, we are often helpless, because the various strains of bacteria are able to modify their

response to our bactericides faster than we can produce new drugs. The ravages of malaria remain: thousands of children die each day from this disease. There is now a new nightmare, the possibility of a mutation leading to a bird flu strain that has the potential to kill millions of people. Throughout all of this, there is the overwhelming presence of the pharmaceutical paradigm, the twentieth century concept that assumes that for every medical problem there is a pill that can help.

It is clear that there is a serious problem with medicine as practiced in the twenty first century. Obviously the twin pillars of modern medicine, pharmacology and surgery, do work to some degree: they do help many sick people. But, considering all the money and talent that have been poured into medicine it is far from where it should be.

How to resolve this criticism of modern medicine, where we find an over abundance of individual solutions but no overarching way of connecting these solutions? How do we resolve this matter of empiricism versus synthesis?

Our approach is based on trying to describe the biological system in electromagnetic terms. We use the fact that any living system carries charges and currents in each of its components, such that the sum total of these can be used to form a unique field vector. This immediately gives us a holistic description of the entire system. Above all, it is a field concept, a descriptive arrangement very familiar to the physicist. Michael Faraday first made use of electric and magnetic fields in the 1830s and a few decades later Maxwell showed that the electromagnetic field is a very real entity, something that is always produced by the existence of electric charge and current. Now it has become commonplace to express all physical phenomena in terms of fields. There is the gravitational field, the nuclear field, etc. We are suggesting that the life process itself is an expression of the electromagnetic field.

Formalizing the Field

Characteristics of the field. For any system, living or not, electromagnetic fields only exist when the system contains charges and currents. It is common to speak of these as sources of the field, and to express these sources in terms of their densities, specifically the charge density per unit volume and the current density per unit area.

For all but some exceptionable cases the fields that are produced by living systems are almost always regarded as non-detectable. Exceptions include the electric and magnetic fields generated by the nervous system (e.g., EEG, MEG, EKG, MKG) where currents act in large scale concert to implement specific organ function. But, aside from such cases the overall field created by the entire ensemble of charge and current sources within a living thing is rarely discussed because it is so weak. Not only is this field considered unimportant because it is not readily detectable by experiment, but it is also considered non-detectable by the system itself, since the system generates an inherent electrical noise due to thermal oscillations that will swamp out the net effect of the field created by the source densities.

This argument was first raised in a slightly different context, where it was used to set lower threshold limits on *externally* applied electromagnetic signals in the presence of competing signals due to thermal noise.

However, it is now abundantly clear that living things can respond to ultra weak electrical and magnetic signals, some, as recently determined of the order of 100 to

1000 times less than theoretically predicted lower thresholds. We now know that the question of biological detection of ultra weak electromagnetic signals is far more subtle than heretofore realized.

Electric polarization as a key variable. Many of the reports in the Introduction suggesting a functional relationship between electricity and the living state can be regarded as effects related to electric polarization. The Polarization vector $\mathbf{P}$ is equivalent to the dipole moment per unit volume. It is closely related to the Electric Field vector $\mathbf{E}$, in most cases sharing the same distribution in space.

The primary source of electric polarization $\mathbf{P}$ in eukaryotic systems is the capacitive double layer associated with cell membranes.

Polarization was explicitly measured in the experiments by Athenstaedt (1969) and by Fukada and Yasuda (1957), but it was also implied in the work of Lund (1947), Burr and Northrup (1935), and Becker (1974). One additional example is found in the work of Jaffe and his students (1968, 1974), where endogenous currents were carefully mapped in the vicinity of individually growing embryonic systems. These results found that these currents flowed in a manner corresponding to a dipole field distribution.

The $\mathbf{\Pi}$ vector. One way of expressing the total intrinsic electromagnetic field of any living organism is to associate the Hertz vector $\mathbf{\Pi}$ with this field. This is especially convenient if one believes that electric polarization is the key to understanding the relation between electromagnetic fields and life, because $\mathbf{P}$ represents the source of $\mathbf{\Pi}$. In other words, the vector field $\mathbf{\Pi}$ is composed of all the individual dipole moments $\mathbf{P}$ distributed within the system, such that

$$\pi = \frac{1}{4\pi\epsilon} \int \frac{P}{r} dV \quad (1)$$

where the integration is performed over the volume of the system, ϵ is the dielectric permittivity, and r is the distance from each dipole moment to the point in space where π is being determined.

In this way, one obtains a unique representation for any living thing, a vector field determined by the distribution of electric polarization within the system. This vector field can, in principle, be described at any point in space within or outside the system. Because the polarization $\mathbf{P}$ can vary in time, $\mathbf{\Pi}$ itself changes in time.

Because of this we can hypothesize that $\mathbf{\Pi}$ is a function of both phylogenetic and ontogenic time. This field grows with us as we develop and age, and is itself the product of evolution, relating each of us to our species and all that came before. The field described by $\mathbf{\Pi}$ reflects the changes in the developing embryo, and those that occur as we further develop.

This begs the question as to whether there is any connection between $\mathbf{\Pi}$ and the genome. One way of entertaining this speculation is to suggest a formal transformation between the genome and $\mathbf{\Pi}$. We can think of the genome as G , a dimensionless function that basically operates on, or in more familiar terms, codifies, the system-to-be. We represent the latter as another vector function $\alpha(\mathbf{P}, t)$, where $\mathbf{P}$ is the electric Polarization and t the time, measured since conception. If the species designation is labeled with the subscript i , then one possible trial transformation for

the i th species is

$$\pi_i = G_i[\alpha(\mathbf{P}, t)] \quad (2)$$

The Π field will also reflect changes due to trauma or illness. In accordance with Becker's interpretation of Matteucci's current of injury, such disturbances to the intrinsic field will serve as a template for restoring the system to its normal state.

The Wellness Postulates

Given the hypothesized field description, it becomes possible to frame a statement about wellness directly in terms of this field (Liboff, 2004). This is expressed in the following pair of postulates:

1. Every living organism is completely described by an electromagnetic field Π specifically determined by a transformation from the organism's genome.
2. All pathologies, abnormalities, and traumatic changes in the organism are manifested by deviations from its normal field Π , and within limits, these deviations are compensated for by the homeostatic tendency of the system to return to Π .

The Geomagnetic Field and Man

It is reasonable to anticipate that if living things are essentially electromagnetically ordered systems then the most environmentally pervasive of all electromagnetic variables, namely the geomagnetic field, must play an important functional role in biology. However, the GMF intensity is small, of the order of $50\mu\text{T}$, and it is not immediately clear what sort of interaction process can be involved in such functionality. It is clear that birds and turtles and many other species make use of the GMF for navigational purposes, but the underlying interactive mechanism remains a mystery.

There is now strong reason to believe that the GMF couples to living things through a resonance interaction. There are three well-studied electromagnetic resonant effects, NMR, or Nuclear Magnetic Resonance, ESR, or Electron Spin Resonance, and ICR, Ion Cyclotron Resonance. Each requires the simultaneous application of two signals, one static and the other oscillating. The resonance frequencies in NMR and in ESR are rather high, since they are coupled to nuclear spin and electron spin, respectively. However much lower frequencies are possible in ICR applications, especially those involving massive charged particles such as ions. It turns out that for static magnetic fields of the order of the GMF, the resonance frequencies predicted for biologically significant ions such as Ca^{2+} , K^+ , and Mg^{2+} (See Fig. 1) are less than 100 Hz.

The ICR biointeraction (Liboff, 1985, 2005) has a number of remarkable features that have already made it medically useful. For example, ICR makes it possible to manipulate the physiological activity of key biological factors such as Ca^{2+} , K^+ , and Mg^{2+} as well as other ions by applying certain calculable magnetic frequencies. The ICR interaction is quite distinct from what is done using pharmaceuticals, where physiological activity is altered by adding agents in the form of pills, injections, or osmotic pads. Accordingly some refer to this approach to medicine as *electroceutical* as opposed to *pharmaceutical*.

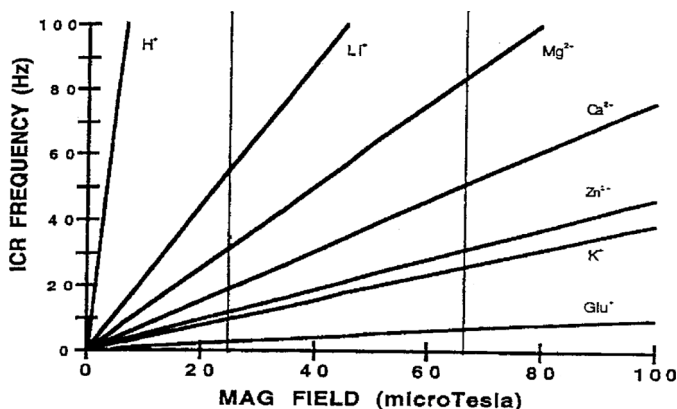


Figure 1. Ion Cyclotron Resonance frequencies for a number of common cations, plotted against magnetic field. The two vertical lines represent the lower and upper limits of the earth's magnetic field, corresponding to the field at the geomagnetic equator and at the geomagnetic poles, respectively.

Physiological effects from ICR magnetic field combinations are observed when (1) DC and AC fields are simultaneously applied to living organisms, (2) certain constraints on directionality are observed for these two fields, and (3) the frequency of the AC field is dependent on the DC intensity.

We hypothesize that the GMF control of living things, derived over millennia of natural selection, fits these criteria: one can readily find directional components of the GMF that are consistent with endogenously occurring electric or magnetic fields. The frequency constraint turns out to be greatest in the extremely low frequency region that is associated with physiologic activity in the brain and throughout the body. These frequencies are readily obtained from the simple expression for which the ratio of AC field frequency ω to DC field intensity B equals the charge to mass ratio q/m of the ion that is stimulated. Mathematically this is written as $\omega/B = q/m$.

Experimentally, because the values of the various biological ions are readily available from physical tables, one can adjust the frequency and field to correspond to any given ion. Thus the frequency and the intensity of the combined magnetic fields that are applied are uniquely dependent on the ionic type. This makes ICR technology completely different from any other type of technology used in magnetic therapy.

Furthermore the **ICR** relation to the GMF is not only a theoretical possibility, but it has already been demonstrated in dozens of experiments for which the GMF is readily incorporated into the design to serve as the DC component of the required combination. By careful adjustment of the AC frequency in the local earth's field, one can "tune" the frequencies to individual ions. In this way, experiments have been done on whole organisms, in cell culture, on specific regions of the body, and even on plants, in all cases resulting in gross physiological changes.

Because the field combinations are directly tied to the charge to mass ratio of the ion, following the expression $\omega/B = q/m$, we can list these combinations as shown in Table 1.

Despite abundant evidence showing the existence of ICR-like physiological effects at ultra low field intensities, as yet there is no reasonable theoretical

Table 1
Cyclotron resonance characteristics for
selected cations

Ion	q/m (C/kg) $\times 10^{-6}$	f/B (Hz/ μ T)
H ⁺	95.76	15.241
Li ⁺	13.90	2.212
Mg ²⁺	7.937	1.263
H ₃ O ⁺	5.066	0.807
Ca ²⁺	4.814	0.766
Zn ²⁺	2.951	0.470
K ⁺	2.467	0.393
Arg ²⁺	1.235	0.197
Asn ⁺	0.838	0.133
Glu ⁺	0.747	0.119
Tyr ⁺	0.591	0.094

explanation that describes how this interaction works at the molecular level. A number of models have been advanced but they have all been found wanting. In some respects the situation is similar to the century-old introduction of aspirin as a pain reliever, where its efficacy was established long before the explanation of how it works.

In any event, it follows conclusively from the great many experiments, many of them independently confirmed, that the application of Ion Cyclotron Resonance magnetic fields to living things can profoundly alter the physiologic outcome in predictable ways. This has potentially explosive indications for medicine.

Local and Holistic Therapies

Ion Cyclotron Resonance was first used as a therapy to treat the problem in bone known as nonunion (or pseudarthrosis) where bone fails to properly knit after a fracture or where because of a congenital defect bone development is incomplete. Also, a second therapeutic application has been as an adjunctive procedure following spinal surgery to speed recovery. Both applications are approved by the US Food and Drug Administration (FDA) and are highly efficacious, on the order of 70–80% successful. These therapies are strictly local, with the ICR device placed such that the magnetic fields that are generated are directed into the problem areas.

The components of the earth's magnetic field (GMF) are measured in the problem area and the frequency of the sinusoidal magnetic field that is imposed parallel to one of the GMF components is tuned to achieve resonance for the charge to mass ratio of the calcium ion. This tuning procedure makes use of the formula mentioned above, $\omega = qB/m$.

By contrast the Seqex device, invented by Valerio Dallago and Claudio Poggi, applies the ICR magnetic field to the entire body, and is therefore the first example of a procedure designed to provide ICR systemic or holistic therapy.

As in the earlier ICR work the Seqex device uses the GMF to obtain resonant conditions. Ankle and foot electrodes enable one to obtain the whole body

impedance during the entire procedure, which lasts for 27 minutes. The patient is maintained face up, in a horizontal position, so that the vertical component of the GMF is everywhere perpendicular to the plane of the body. Coils are positioned within the bed to direct an oscillating magnetic field through the patient in the vertical direction. When these weak low frequency magnetic signals are applied, the impedance spectrum changes at the ICR frequencies.

This lengthwise bioimpedance, carefully determined as a function of the applied frequency, in effect provides a spectral distribution, unique to the individual, and is catalogued as the patient's "wellness factor". These whole body ICR frequencies form the basis for subsequent treatments. The remarkable aspect of this technology is the coherent response of the body impedance to these ICR frequencies.

Impedance is a physical variable that consists of three components: resistance R , inductive reactance X_L , and capacitive reactance X_C . It is usually assumed that living things have no measurable inductive reactance, only resistance and capacitive components, resulting in a net impedance Z is determined by just two factors.

$$Z^2 = R^2 + X_C^2. \quad (3)$$

Further the resistive part of any bioimpedance measurement is mainly due to the skin resistance, where the electrodes are located.

Thus it is reasonable to infer that the capacitive reactive component of the bioimpedance is sensitive to the ICR resonance frequencies, a discovery that has important implications. The capacitive reactance X_C is usually defined as $(\omega C)^{-1}$, where ω is the frequency and C the capacitance.

A tentative explanation for this ICR effect is found by considering the origin of the capacitive reactance in measurements of bioimpedance. The capacitance in such measurements is undoubtedly found in the insulating double layers surrounding the cells in the body. There are equal and opposite distributions of charge on these layers. The resulting dipole moment integrated over all the cells in the body lying between the electrodes thus determines the net capacitive reactance that one measures.

Our approach to the ICR problem has been that resonance frequencies will initiate physiological messages by displacing ions across the cell membrane, altering its charge balance. Therefore one explanation for the Dallago/Poggi observations is that ICR frequencies tend to affect the dipole moment of cells in the body thus changing the capacitive reactance component of the bioimpedance. This picture is consistent with the formalism given earlier that suggests an electromagnetic field vector $\mathbf{\Pi}$ as a measure of the living state. The overall dipole moment per unit volume is equivalent to the electric polarization vector $\mathbf{P}$, which is the source of $\mathbf{\Pi}$.

The Dallago/Poggi device is very different from previous ICR devices. It provides a means for both measuring an individual's electromagnetic state as well as adjusting it. Because both the measurement of this state as well as the application of the magnetic adjustment are made in terms of the entire body, the nature of this device is truly holistic.

Discussion

There are a number of things quite profound in this new formulation. First, there is the realization that the overall electric polarization of the body can be a

useful measure of wellness. Second, it has been observed that the body's electric polarization can be dramatically changed by the application of ICR magnetic fields, and third that such changes, when made properly, can result in the improvement of one's wellness.

These are far-sweeping statements that tend to reinforce the overarching concept that life, at its core, is an electromagnetic entity.

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